TEST AND ON-ORBIT EXPERIENCEES OF FALCONSAT-3

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ABSTRACT

The fundamental objectives of the capstone design project in the Department of Astronautics at the United States Air Force Academy (USAFA) are for cadets to learn important engineering lessons by executing a real space mission on a Department of Defense-funded satellite project. FalconSAT-3 is a 50 kg, gravity gradient-stabilized designed and built by cadets and launched March 2007 on the first ESPA (Enhanced extended launch vehicle Satellite Payload Adapter) mission. FalconSAT-3 was one of six satellites integrated onto the launch vehicle and the nature of the mission made it that the satellite was subject to the full formality of testing requirements. Two successive gravity gradient booms failed either design requirements or environmental testing; design requirements grew dramatically during the design phase; ambiguous thermal vacuum test results led to uncertainty at launch; and after launch it was not possible to contact the satellite for several weeks.

1. INTRODUCTION

The successful resolution of these problems, and the continuing on-orbit operations - and software development - has resulted in several hard-won lessons for four successive classes of cadets. This paper will describe and discuss several important issues for academic, small satellite programs. There are several constraints on a satellite program whose primary focus is undergraduate education that lead to interesting design, testing, and operational decisions.

First, uncertainty about launch loads and severe risk avoidance by the Program Office led to vibration testing at 15 grms and detailed finite element analyses that were strenuous for the program. Secondly, the first gravity gradient boom was an experimental "memory composite" device whose first delivery was too, big, too late, and not functional. The "proven" COTS replacement failed miserably and the late procurement of a quality COTS item required obtaining last-minute safety approvals for pyrotechnics and gyrations in the testing program. The original simple software requirements evolved into the need for three-axis control and ambiguous thermal-vacuum testing results

of the flight computer forced the cadets to make critical program decisions as the integration and launch date inexorably marched to its own schedule.

After a successful launch, the cadet ground station was not able to communicate with the satellite for several weeks and the anomaly resolution processes and subsequent recovery and operational experiences have given the cadets an appreciation for why space is hard and we, as space professionals, often can learn from the wisdom of the neophytes. The current state of satellite operations is described with an emphasis on the kinds of significant technical contributions that can be made by undergraduates.

2. DESIGN REQUIREMENTS AND CONSTRAINT

2.1. Mission and Payloads

The scientific mission of the FalconSAT-3 program is to fly three Space Experiments Review Board (SERB) experiments on a Space Test Program (STP) provided launch vehicle. The educational mission of the program is to provide a real-world, Department of Defense (DoD) funded project that teaches cadets about the entire design / build / test / operational cycle of space programs by requiring them to perform as many of these functions and capabilities as possible. The students are
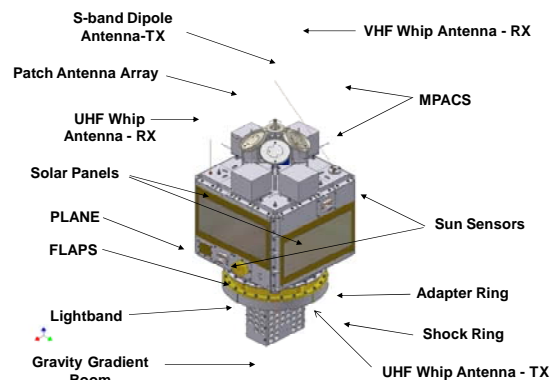

Figure 1. FalconSAT-3 External View

in their fourth year of an undergraduate engineering program and participate in this capstone engineering course for two semesters. There are no graduate

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14. ABSTRACT

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students and the role of the faculty, and a very small number of contractors, is to teach and mentor and only do those tasks that are reasonably beyond the abilities of undergraduate engineers.

Figure 2. FalconSAT-3 Mission

The satellite was required to support five separate payloads. The two primary SERB payloads were plasma instruments known as PLANE and FLAPS. PLANE (plasma local anomalous noise environment) is a new plasma sensor developed in the Space and Atmospheric Research Center (SPARC) in the Department of Physics at USAFA and is designed to measure the boundary layer effects on plasma flow around a spacecraft. FLAPS (flat plasma spectrometer) is another plasma instrument (jointly developed with SPARC, NASA and JHU/APL) and it is designed to measure and understand ambient plasma morphology such as "plasma bubbles" and other inhomogeneous structures in the background ionosphere. The third payload is MPACS, which is a miniature pulsed-plasma thruster, and the goal is to demonstrate operation on orbit. The fourth payload was an experimental composite gravity gradient boom and the fifth payload was a shock ring adaptor that was intended to reduce the high frequency vibration environment that coupled into the satellite during launch.
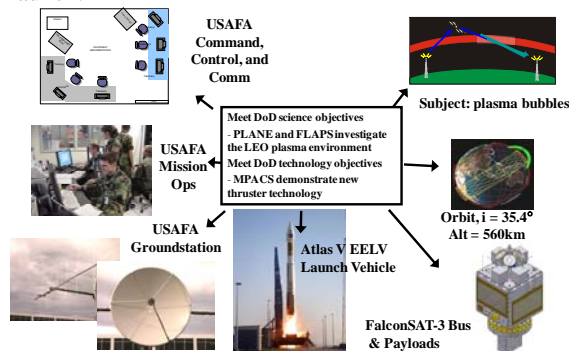

Figure 3. FalconSAT-3 Mission Architecture

The orbital requirements for the satellite were a 560 km circular orbit at a 35.4^0 inclination. The only ground station for this satellite is at USAFA at latitude 39^0 and that has made closing the link budget and successful communication difficult to manage.

2.2. Launch Vehicle and Programmatics

The launch vehicle chosen for this mission was an Atlas V heavy-lift rocket that had the Orbital Express satellite as its primary spacecraft. The launch vehicle was also required to fly the first ESPA ring, which has been designed to accommodate as many as six secondary satellites. The ESPA Users Guide [1] defines the general requirements for the secondary spacecraft and those are summarized in Tab. 1.

mass	181 kg
volume	60.96 x 71.12 x 96.52 cm
Centre of gravity	50.8 cm from mounting
Fundamental frequency	> 35 Hz

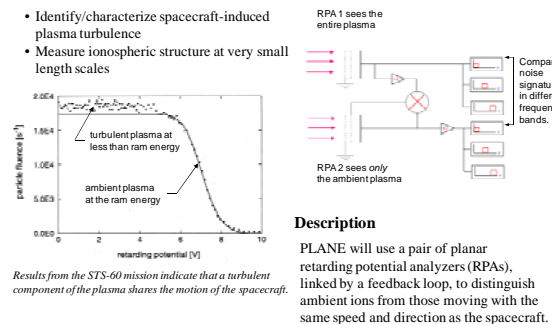*Table 1 ESPA Requirements*

Figure 4. PLANE Objectives

The mounting ring separation system required for this mission was a 15 in (38.1 cm), 24-bolt motorized (or non-motorized for FalconSAT-3) lightband from Planetary Systems Corporation (PSC). This system eliminates the pyroshock from a pyrotechnic initiated separation system and provides a controlled, spring force-driven separation from the launch vehicle.

Figure 5. FalconSAT-3 mounted on ESPA Ring

Because of the complex nature and importance of the primary spacecraft on this mission FalconSAT-3 was required to meet all of the safety requirements imposed by the integrating contractor (IC), the launch vehicle

provider, the Eastern Test Range (ETR), and STP. From an educational perspective the insights gained by cadets into the complexity, and bureaucracy, of the aerospace industry was extremely enlightening. From the perspective of a small team building a satellite the documentation, analyses, and reporting requirements became a daunting task unto itself.
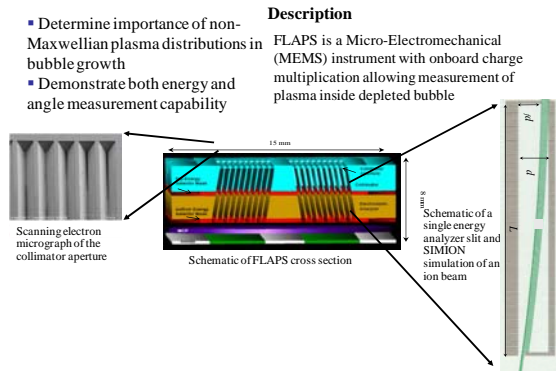

Figure 6. FLAPS Objectives

2.3. Academic Schedules

The schedule of the students is dictated by the USAFA academic calendar and their numerous duties and responsibilities outside of the classroom. The schedule of the satellite is dictated by the sponsor providing the funding and launch and integration schedule of the primary mission satellite. In addition, the nominal four year period from start of the project to launch and early on-orbit operations involves four separate graduating classes of students who annually depart in May before their replacements from the next class arrive in August. This one hundred percent turnover in the workforce every year makes project documentation absolutely critical to the success of the program – and one of the most important lessons the students will learn.
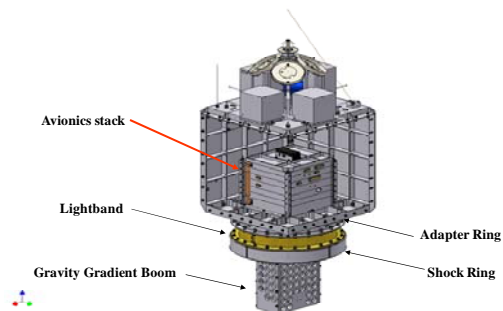
2.4. Life of a Secondary Payload

Figure 7. FalconSAT-3 Internal View

In order for a secondary payload to receive the maximum probability of being manifested on any launch vehicle it must be designed to require the absolute minimum effort to be integrated and limited services after encapsulation. As a result FalconSAT-3 was designed to be powered OFF after encapsulation

and to require no services except the ability to charge batteries every 30 days. This ensures that the satellite can be launched into any lighting conditions. The last functional test of the satellite is prior to integration and there will be no further state of health information from the satellite until communication is established sometime after separation on orbit. While in theory the satellite could be launched with dead batteries and then be charged on-orbit before any operations can commence, that additional risk is unnecessary as long as is it possible to charge the batteries. For this launch that meant the ground crew connected to the FalconSAT-3 batteries through a 500 foot umbilical cable. This class of satellites waits until the launch vehicle separation switch is tripped on orbit and then battery power is connected to the critical components.
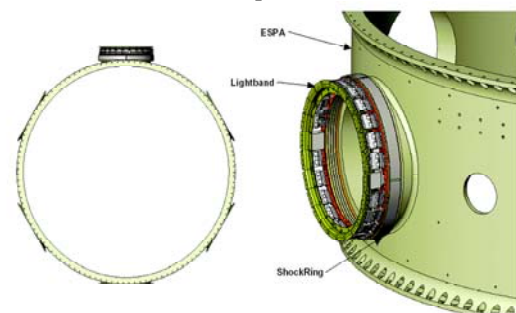

Figure 8. Shock Ring and Lightband

3. TESTING CAMPAIGNS

The development philosophy of the Smallsat program at USAFA is strongly focused on testing at several stages. While the students are required to do as much theoretical and analytical design as is reasonable at the undergraduate level the critical educational goals are best met by: extensive emphasis on assembly procedures and practices; integration at the subsystem, system, spacecraft, and launch vehicle level; and, testing at all levels.

3.1. Test Articles

Typically the testing approach includes four separate stages. The first stage is the construction of a physical model. The physical model can be constructed of cardboard or plywood and serves as a means to visualize what the spacecraft will look like and how payloads, avionics, and wire harness can be accommodated. This is where the initial trade-off studies and design decisions are made.
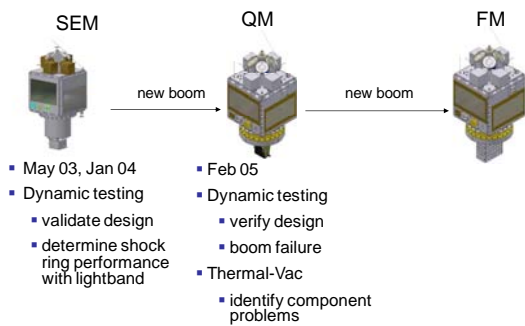
SEM QM FM

new boom → new boom →

- May 03, Jan 04
- Dynamic testing
  - validate design
  - determine shock ring performance with lightband

- Feb 05
- Dynamic testing
  - verify design
  - boom failure
- Thermal-Vac
  - identify component problems

Figure 9. FalconSAT-3 test Sequence

The second major item is a structural engineering model (SEM). The SEM is a duplicate of the satellite structure that will be flown and the avionics and payload components are simulated using mass dummies. The mass and volume of the SEM are the same as the flight model and are subjected to a vibration and shock environment that determines whether or not the structural design is adequate to handle the launch loads. The SEM test is also instrumented well enough to identify variations in the defined launch load environment that can be seen at various places in the structure.

➢ **Technology demonstration of precision-controlled, low-thrust micro plasma pulsed thrusters for future attitude control applications**
➢ **Operate MPACS in excess of 90 hours on orbit**
  • **Firing 9/12 thruster tubes due to FM test results**
➢ **Determine thrust provided by MPACS by measuring change in satellite dynamics**
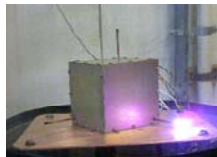 • **Yaw axis will achieve best results based upon sensor accuracy**

Figure 10. MPACS Objectives

The development philosophy of the program is that it is more productive to build a complete, working qualification model (QM) of the satellite rather than focus on individual component testing. This fits very well within the academic structure and allows one class to build a working satellite that is subject to qualification levels. The avionics in the QM also serve the purpose of an avionics test bed (ATB) that is used for software development, operator training, and on-orbit anomaly resolution.

The last item built is the actual flight model (FM) of FalconSAT-3 and that is subjected to acceptance level testing for vibration and shock and for thermal cycling inside a vacuum chamber. The facilities at USAFA are limited and for each of these major tests the satellite is transported to Kirtland Air Force Base (KAFB) in Albuquerque, New Mexico where the large shaker tables and thermal-vacuum chambers are used. While

antenna test ranges have been used to determine the gain patterns off antennas on the spacecraft controlled EMI/EMC test are usually not conducted.

3.2. SEM and QM Environmental Testing Results

The SEM and QM tests were very successful in qualifying the structure and in uncovering potentially catastrophic failures that would have inhibited on-orbit operations. The first issue identified during vibration testing was that a small UHF whip antenna could resonate in a mode that caused it to get inadvertently captured in the structure of one of the S-band antennas. This was quickly fixed after testing by configuring the UHF antenna in a different orientation. The second issue was more severe and significantly impacted the program.

The original design of the satellite included a gravity gradient boom that was a research and development endeavour of Air Force Research Laboratory (AFRL). The vendor providing a composite memory material delivered the item several months late, non-functioning, and not meeting the required mass and volume constraints. The educational value to the students in dealing with research and development activities was very significant but also caused them to pursue other alternatives. The second gravity gradient boom procured was supposed to have significant flight heritage. However, after that boom arrived and underwent testing it failed at very low levels of vibration. The cadets attempted several fixes of the boom but the design and manufacture were fundamentally flawed and after several months of effort – and launch vehicle integration rapidly approaching – the cadets were forced to initiate an emergency procurement of a more sophisticated COTS gravity gradient boom with a long heritage of successful flights. However this also required a change from an electromechanical release mechanism to one that used pyrotechnic cable cutters. While this was a standard technique in the industry it was a last minute change to all of the safety submittals to the launch vehicle integrator and range safety office. That became the definition of another learning opportunity for young engineers.

The new vendor was required to demonstrate successful deployment and the satellite team was required to develop and test a new firing circuit. This was the one exception to the general testing philosophy where the components were qualification and acceptance tested as components and bolted onto the satellite after final acceptance testing of the FM.

One other object of the SEM and QM environmental testing was to determine what performance of the shock ring was required. The use of a lightband as a separation system meant that the satellite fundamental frequency would appear to be lowered since the compressed

lightband does have some lower frequency modes than the relatively stiff aluminium box that comprises the satellite body. The instrumented results of the SEM indicated that the response function of the shock ring needed to be modified. Analysis of the test data allowed the vendor to re-design a different response function into the shock ring and the result of that effort was a successful QM test.

The thermal cycling testing in the vacuum chamber went from -20 C to 50 C to qualify the components and all components functioned properly. The real benefit of this full environmental testing of the QM was that assembly and integration of the FM could proceed as planned.

3.3. FM Environmental Testing Results

For a secondary payload on a complex launch the successful completion of the environmental testing is absolutely critical to the launch vehicle integrator since this is what ensures that the secondary satellite introduces no risk for the launch vehicle or primary payload. Any hint of risk and the secondary payload will be immediately removed from the flight manifest and required to provide a mass dummy of the satellite to ensure that all of the previously calculated rocket loads are constant. As an aside, the requirement for a secondary payload to provide a substitute mass dummy in the event that the FM cannot be delivered is a significant cost to a small satellite program.
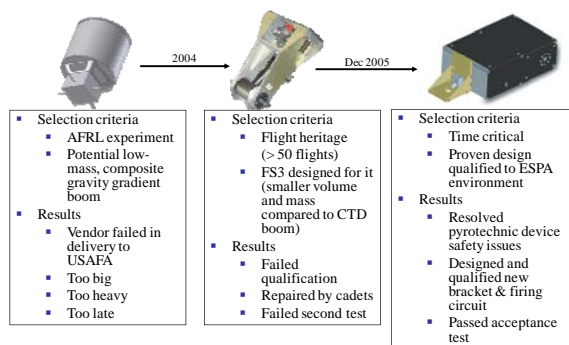
Figure 11. Gravity Gradient Boom History

As FalconSAT-3 FM was completed and prepared for environment testing the previously mentioned problems with the gravity gradient boom had been identified and resolved and the testing schedule for the FM had to proceed without the boom. As a result a mass dummy of the deployable boom was used during acceptance testing of the FM. The vibration testing of the satellite was successfully completed and the satellite completed all functional testing.

However, after the FM satellite went into the vacuum chamber two component failures appeared. The first failure was that only 9 of the 12 MPACS tubes were able to fire. There was a custom FPGA driver circuit for

all of the MPACS tubes and it appeared that one or more output gates of the FPGA probably failed. The dilemma at this time was that the satellite structure, the avionics stack, and the tray with the firing circuit would have to be disassembled. That level of disassembly would require a complete retesting of the satellite to acceptance levels after repair (if possible given schedule constraints) and it was determined that the extra testing cycles of the satellite would introduce risk into the program. Unfortunately for the MPACS principal investigators that meant the satellite would launch with 25% of the experiment non-functional. From an educational perspective it was one more important learning experience for the team of how they must balance cost, schedule, technical risk, and program risk.

- NGST boom has new pyrotechnic release device
- New firing circuit designed, built, and tested at USAFA
- Inadvertent boom deployment and pyrotechnic safety issues resolved in Mission System Program Safety Plan (MSPSP) process
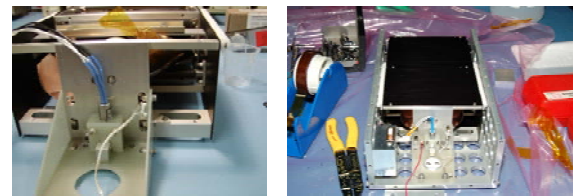
Figure 12. New Pyrotechnic Firing Circuit Added

The second failure in thermal cycling was more troubling and more ambiguous. Acceptance testing of the FM was done between -10 C and 40 C since the expected on-orbit environment was 0 C to 30 C. After cold soaking at -10 C, the flight processor (IFC) failed to start when the separation switch was tripped. This test was repeated several times and in every instance the IFC would eventually power ON when a temperature of ~5 – 7 C was reached. This anomaly could not be replicated on the QM avionics (which had worked at -20 C) and provided the cadets with a hugely important risk analysis task to perform. FalconSAT-3 was to be the last satellite to be dropped off after approximately 40 minutes and was exposed to either darkness of sun during that time as a function of when the launch actually took place. The Lockheed and Boeing teams had performed detailed thermal analyses for the secondary payloads and the worst case for FalconSAT-3 indicated a possible cold temperature of 5 – 7C; exactly where the dividing line between success and failure occurred. The cadets formally evaluated the risks of: assembly / disassembly (impact on future testing); successfully troubleshooting the circuit (what if it was a thermal transient that could not be repeated?); schedule (could there be a replacement in time from the vendor?); budget (already tight with minimal margin); and probability of the IFC surviving this environment with no changes. The cadets weighed these considerations and decided to launch and integrate as is.

4. LAUNCH VEHICLE INTEGRATION

The integration of FalconSAT-3 onto the launch vehicle was a simple as had been planned. Functional testing of the satellite revealed that all systems were operating as expected and a lifting harness allowed for the satellite to be lifted off of the shipping container and rotated 90 degrees for integration onto the ESPA ring. 24 bolts, and two connectors later, the satellite was fully integrated and ready for encapsulation. The flight harness was connected and the battery voltage was checked and the battery was found to be fully charged.

Figure 13. STP-1 Mission Configuration

The battery system on FalconSAT-3 consists of seven NiCad 'D" cells rated at 4 A-hr each. These batteries have a significant flight heritage and have proven to be remarkably robust. The flight cells used in the satellite were only three years old at the time of launch and had plenty of shelf life left. Testing with the batteries indicated that there was a self discharge rate less than 0.75 mV/hr. However when the batteries were checked just prior to encapsulation 6 weeks later, the battery voltage had dropped to less than 1.0 V on a nominal 9.8 V power bus. The battery voltage should have been approximately 8.1 V and this complete discharge of the batteries to approximately 0.1 V per cell was the source of significant concern. Initial attempts to re-charge the batteries through the umbilical cable were only partially successful until the charging procedures were changed to reflect the increased resistance of the 500 foot cable. The batteries were very carefully charged (while monitoring temperature) and the apparent discharge rate was measured for several days. For reasons that are still not clear (leakage in the cable?, spacecraft internal faults?). The batteries now demonstrated a 10x increase in discharge rate to 6.6 mV/hr.

The decision at this point was simple – leave the satellite as is for encapsulation and charge the batteries every few days instead of every 30 – 60 days as had been planned.

5. EARLY ON-ORBIT OPERATIONS

The launch of STP-1 occurred at Kennedy Space Center on 8 March 2007 and the nighttime launch was spectacular for both its vivid plume and the fact that every one of the satellites was separated on time and in the correct orbit. FalconSAT-3 was the last satellite separated and the initial state vectors were relayed to the ground station at USAFA. First contact could not occur for several orbits.
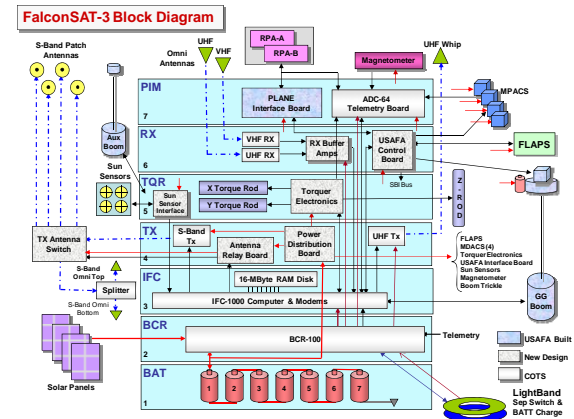

Figure 14. FalconSAT-3 Block Diagram

The planned operational sequence for FalconSAT-3 was to turn on the IFC and the receivers (VHF and UHF) immediately after separation. The sequence is as follows:

1. Power to the IFC causes it to execute the bootloader code in the processor PROM
2. The PROM containing the bootloader code is socketed and has been tested extensively on both the QM and FM versions of the satellite
3. The bootloader writes the base flight code from FLASH (EPROM) memory into the error detection and correction (EDAC) memory.
4. The flight code then starts executing and waits for the first command received from the USAFA ground station to turn on the transmitter and start broadcasting telemetry.

6 hours after separation the USAFA ground station attempted communication with FalconSAT-3. No signals at all were detected on the spectrum analyzers. TLEs were checked and for the next several days attempts were made to communicate with the satellite on both the UHF and VHF uplinks with no indications at all of any signals from the satellite.

The operations crew also made several attempts to reset the IFC using a "firecode" signal that sends a simulated watchdog timer reset to the CPU. Unfortunately this is not a true watchdog timer reset since there is no power

cycling of the processor. This signal resets the vectors on the CPU in the IFC and clears the states to a supposedly known state.

After a firecode reset signal to the satellite the bootloader starts its initialization and flight code loading sequence. If that process can be interrupted within 30 seconds of a reset then the IFC executes just the simple bootloader commands. Since USAFA did not have access to the source code of the bootloader the vendor was enlisted to attempt communication with the satellite. The vendor was able to reset and then freeze the bootloader process so that it became possible to communicate with what is essentially the BIOS on the satellite processor.
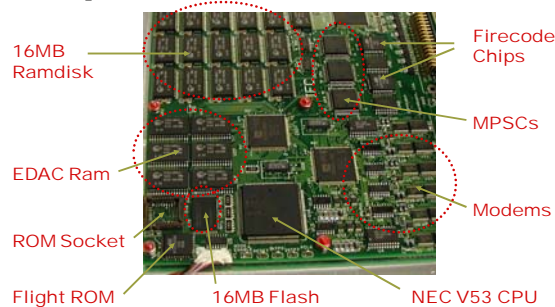

Figure 15. FalconSAT-3 IFC

The anomaly resolution process had started formally after failure to communicate with FalconSAT-3 but no data of significance could be accomplished until there was some form of rudimentary communication. Possible causes of the anomaly identified included:

1. Transmitter or receiver failure: This was the only redundant system and all of the hardware had an extensive flight heritage.
2. IFC cold start failure: While ground thermal testing had uncovered this problem there was never a case where the IFC failed to start after warming past 7 C – and the predicted temperature during a sunlight pass over the ground station exceeded that point.
3. Software: Some how the bootloader code was corrupted but that was in the most reliable memory (PROM) on the spacecraft.
4. Separation switches some how did not operate but they are mechanical devices and the satellite was definitely separated from the launch vehicle.
5. Power: Somehow the batteries had become completely discharged in 24 hours and were not capable of recharging on orbit; but the battery discharge rate monitored prior to launch was small enough to allow for ten days of holding capacity.
6. Flight code corrupted in FLASH memory: but this chipset had been extensively tested with no failures.

When communication with the bootloader program was established it did provide limited telemetry that determined the battery voltage and temperature were normal and that there were no obvious hardware failures. The next question was to determine why the satellite could not successfully load and execute the flight code.
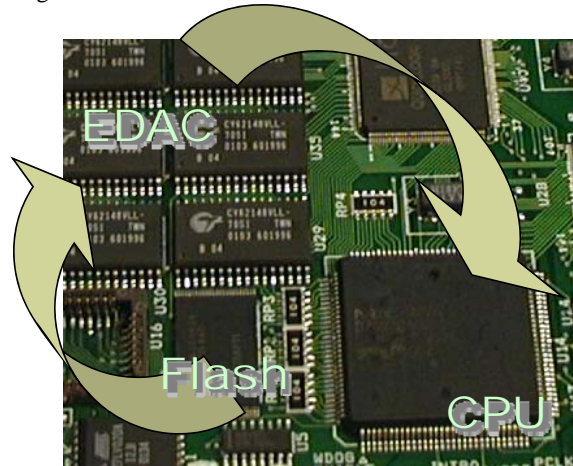

Figure 16. FalconSAT-3 Boot Sequence

The next step in the anomaly resolution process was to download a memory map of the flight code in the FLASH memory. As soon as that was accomplished and the memory map examined it was clear that the FLASH memory had some how been dramatically corrupted sometime after the last functional test prior to encapsulation and before 6 hours of post-separation activity on orbit. An examination of the pattern of memory corruption made it unlikely that a radiation event had been responsible. At this point it was not clear whether or not that section of FLASH memory had been permanently damaged. It was deemed advisable to contract the vendor to provide a "crutch" modification to the bootloader code that would enable an upload of new flight code to a different part of FLASH. That crutch program was delivered to USAFA; the original flight code was uploaded to a different part of FLASH and then commissioning was able to begin 25 days after launch.

It is impossible to overstate the value of the educational lesson for the students in this situation. This was, and is, a real mission with a paying customer and not just a homework exercise. With appropriate guidance from faculty and various professionals in the industry the cadets were able to thoroughly explore a variety of causes and slowly work through the problems and recover satellite operations.

6. OPERATIONAL CHALLENGES

Once commissioning was started the procedures developed by the cadets were followed to determine the

state of health and functioning of all systems on the satellite. The magnetometer and torque rods were individually tested and appeared to be working normally. When the first control mode was initiated to de-tumble the satellite it was immediately apparent that the torque rod magnetic fields were completely swamping the magnetometer and rendering that output useless. This had been tested on the ground and there was no interference but on orbit there was a different response. A modification to the flight software was written that turned the torque rods OFF whenever the magnetometer was read. That fix solved the corrupted magnetometer reading problem and the remaining systems functioned as expected.
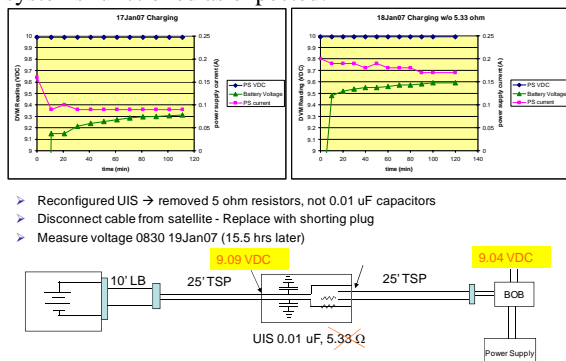

- Reconfigured UIS → removed 5 ohm resistors, not 0.01 uF capacitors
- Disconnect cable from satellite - Replace with shorting plug
- Measure voltage 0830 19Jan07 (15.5 hrs later)

Figure 17. Battery Situation After Integration

At this point the gravity gradient boom was not yet deployed and the science payloads were run through diagnostic modes to determine their operability. As the pace of ground operations picked up and more and more files were generated on orbit and subsequently downloaded for analysis by the operations crew. On board storage on FalconSAT-3 consists of two, 16 MB SRAM banks that are operated as a single 32 MB file system. The onboard software is designed to delete the oldest file in memory when the file system becomes full. The operators on the ground did not have the ability to selectively delete files from spacecraft memory and free up space for new files. Testing on the ground appeared to confirm proper operation of the memory but operations on orbit suddenly came to a halt when the memory was full and files were not automatically deleted. The net result was a software collapse on orbit that required the operators to re-boot the satellite and clear the memory. The re-boot process now worked well and the operators became very qualified in reloading all of the flight software from the ground at each reset.

One of the unique aspects of space education at USAFA is the existence of a Space Operations academic major. In addition cadets from all academic backgrounds volunteer to learn how to operate the satellite and they have the opportunity to participate in as many operational passes as their schedule allows. The satellite operators are very familiar with the details of the satellite and are expected to be able to handle most types of situations on their own. There is a formally established Operations Requirements Working Group (ORWG) that meets weekly and develops plans for operating the satellites. The operational crew structure is modeled after satellite operations in the United States Air Force and the cadet crews exercise FalconSAT-3 in a manner similar to how they will operate other satellites during their careers.

Several other anomalous events have occurred during the first fifteen months of on-orbit operations that have continued to educate – and stress – the satellite operators and astronautical engineering majors who provide technical backup.
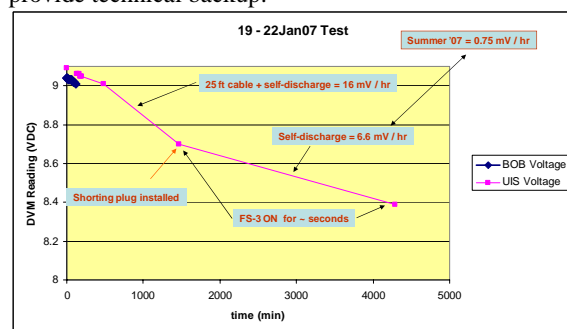

Figure 18. Battery Test Results

The PLANE instrument has worked very well from the beginning of operations and experiments with data downloads are routinely accomplished. Experiments are run on the MPACS payload to determine lifetimes of the individual tubes. Attempts to measure the small amount of torque provided by the MPACS tubes have been unsuccessful to date for reasons associated with the performance of the ADCS system described below.

Extracting useful data from FLAPS has continued to be problematic for several reasons. Diagnostics on the payload seem to indicate that the high voltage power supplies and the micro-channel plate (MCP) are working properly. However, data going from the payload to the IFC over a serial port has experienced random loss of bytes and occasional file writing problems because of the issues with the file system. The file system software has been replaced and the satellite is now able to automatically delete old files to make room for new files. The random loss of data from FLAPS appears to be caused by an unknown source of interrupts to the IFC. FLAPS task software has been modified to run at a higher priority in the operating system with some minimal improvement in performance.

The biggest continuing anomaly is the poor performance of the attitude control system. At launch it

was known that reading the sun sensors in a timely manner too long and was interfering with IFC operations. The software was re-written to operate the satellite control system using only magnetometer input. Cadets wrote variations on Kalman filter that reliably generate good attitude knowledge information with only magnetometer data and those codes have been used on the ground to post-process FalconSAT-3 telemetry. The general limitations of attitude reconstruction using this method involve using linearized models of the satellite dynamics that are only valid when the motion of the satellite satisfies the small angle approximations inherent in a linear model.

The performance of the standard B-dot controller algorithms has been very poor to date and investigations have revealed two problems. The first was a minor software error that resulted in the wrong magnitude command being sent to the torque rods. That was fixed but the performance improved only slightly. At this point it appears that there is a random and subtle disturbance to the magnetometer readings that causes the polarity of the torque rod commands to change quickly and incorrectly. Higher order filters are being written, tested, and prepared for upload to the satellite.

7. FUTURE PLANS AND EXPERIMENTS

FalconSAT-3 has operated on orbit for almost fifteen months and is expected to last at least that much longer on orbit. The fundamental issues uncovered have in most cases been fixed and every one of these experiences has contributed significantly to the education of the students in the program.

Resolution of the final ADCS and FLAPS interface problems will be solved by very carefully backing down the software requirements on the IFC and modifying ADCS software to accommodate the corrupted magnetometer data. The fundamental issue is one of far too many tasks required of the single IFC. This is a 286-class microprocessor without a hardware floating point capability and floating point calculations are done in an emulator. The original requirements for the satellite continued to grow after hardware selection was made and the goal now is to restructure some of the original code to work as well as possible within the limited cycles available.

8. REFERENCES

1. *Secondary Payload Planner's Guide For Use On The EELV Secondary Payload Adaptor*, DoD Space Test Program, July 2006.